Start-Up Plan

for the

Electron Beam Ion Source
(EBIS)

June 2006

1.0 Introduction

The EBIS Preinjector will be located in the lower equipment bay area of the linac building, with some equipment occupying an extension of the building. The preinjector will consist of an Electron Beam Ion Source (EBIS), Low Energy Beam Transport (LEBT), Radio Frequency Quadrupole (RFQ) accelerator, Medium Energy Beam transport (MEBT), a Linear Accelerator (Linac) and High Energy Beam Transport (HEBT). The preinjector will inject the ions into to the Booster via the existing Tandem to Booster (TTB) transport line end at the Booster inflector. This preinjector will provide all the ion species with required intensities to RHIC and NASA Space Radiation Laboratories (NSRL) at 2 MeV per nucleon.

The scope of the EBIS preinjector project includes procurement or fabrication of all components, the assembly of subsystems, and the installation and testing of these subsystems in their final location in the equipment bay at the high energy end of the H^{-} Linac building. The project will be completed upon meeting the technical base line specification given in the EBIS Project Execution Plan.

This preliminary start-up plan follows the facility operation roles and responsibility that have become customary at Brookhaven National Laboratory. The final version of this start up plan will include revisions, if necessary, to conform to the appropriate roles and responsibilities at the time of start-up.

2.0 EBIS Preinjector Performance

The EBIS raises the charge state of ~ singly charged ions injected from an external ion source, or ionizes neutrals from internal gas, to the required charge states by stepwise ionization via an intense electron beam focused by a superconducting solenoid. Ions are trapped in the EBIS by a potential well, created radially by the electron beam space charge, and axially by electrode voltages in the EBIS trap region. When the desired charge state is reached, the axial potential trap is lowered and ions are extracted into the LEBT. The EBIS will provide ions of all the ion species with the desired charge state and required intensities, and will provide a variable pulse length in the range of 10-40 µs. The LEBT is a compact matching line with both electrostatic and magnetic elements for focusing. It is required for transverse matching of the beam into the acceptance of the RFQ, initial injection of ions into EBIS from external ion sources, and direct injection into RFQ from an external source for lower mass ions like D. The RFQ is a four rod structure which will operate at 100.625 MHz. The RFQ is required to bunch the beam and provide acceleration from 17 keV/amu to 300 keV/amu.
The MEBT has magnetic quadrupoles for transverse matching and a buncher for longitudinal matching. The MEBT will provide a matched beam into the linac for all ion species. The Linac, an interdigital-H structure with internal quadrupole triplets for transverse focusing, will accelerate ions from 300 keV/amu to 2 MeV/amu.

Intensity specifications for the EBIS preinjector are established by the RHIC and NSRL requirements, and are listed in Table 1 under “optimum performance”.

3. Validation of Technical Specifications

The functions and performance requirements of the various subsystems are given in the Systems Requirement Document. All EBIS preinjector technical specifications for the subsystems, without beam, will be validated prior to CD-4. Prior to the tests with beam described in this Startup plan, all ES&H requirements will have to be fulfilled and required approvals to operate granted. These items are detailed in the Hazard Analysis Report, and have already been entered into an automated tracking system. This includes requirements such as radiation fault studies, survey for x-rays around all RF cavities, approvals to operate at high voltages, engineering approvals of critical devices, etc.

The technical specifications of the subsystems will be verified either as part of acceptance testing upon receipt of a procured item, validation at time of installation of a subsystem, or as part of a scheduled review. Subsequent validation at the time of CD-4 is not required. Support for these acceptance and validation activities are included in the normal course of procurement or installation and no further project funds are required for their completion.

Table 1: CD-4 performance specifications at the EBIS preinjector Booster input (measured on the Faraday cup located between the two HEBT 73 degrees dipoles).

	CD-4 Performance	**Optimum Performance**
Species	Fe, Au	He to U (assuming appropriate External ion injection)
Intensity	3×10^8 Au^{+32}/pulse 4×10^8 Fe^{+20} /pulse	2.7×10^9 Au^{+32}/pulse 4.0×10^9 Fe^{+20}/pulse 5×10^{10} He^{+2} /pulse
Charge-to-mass ratio Q/m	0.162 (Au) 0.357 (Fe)	≥ 0.16, depending on ion species
Repetition rate	Demonstration of pulsing	5 Hz
Pulse width	10-40 μs	10-40 μs
Switching time Between species	Demonstration of switching	1 second
Output energy	2 MeV/amu	2 MeV/amu

A one page summary, showing each accelerator physics activity, the sum of which constitutes the Start-Up Plan, is contained in Appendix A. Appendix B shows the present schedule for commissioning of the various sections. Initially, the EBIS, external ion injection, and LEBT beamlines are commissioned, with the RFQ not yet put in place to allow room for some temporary diagnostics to be inserted. Following the EBIS/LEBT commissioning, the RFQ is installed and aligned. The RFQ/MEBT is commissioned with a temporary diagnostic box located at the end of the MEBT. This commissioning includes initial longitudinal tuning with the MEBT buncher. Following the RFQ/MEBT commissioning, the Linac is installed and aligned. No extra installation is required between the end of Linac commissioning and the start of HEBT commissioning.

A detailed experimental plan will be developed for each task in this summary table. These details for each step, including curves showing calculated parametric dependencies, will be developed prior to startup, once the detailed physics design of the RFQ and Linac has been frozen. Two examples, (without calculated curves) are shown in Appendix C.

Startup tests will initially be done with He^{1+} and He^{2+} to avoid confusion with multiple charge states.

3.1 Validation of EBIS and LEBT beam specifications

The goal of the EBIS and LEBT commissioning is to bring the EBIS and LEBT to an operational state, and then measure electron beam power and ion beam parameters at the exit of LEBT (entrance of RFQ). First, an external ion beam will be transported to EBIS, with maximum ion current and corrected orbit. An ion beam of the desired charge state will be extracted and transported to end of LEBT. At the end of the LEBT, ion current, emittance and matching parameters into the RFQ will be measured for Au and Fe ion beams, as well as for He^{1+} and He^{2+}.

3.2 Validation of the RFQ and MEBT beam specification

The RFQ will have been previously operated with beam using the prototype EBIS, and the performance characterized. Once installed in the final location, beam will be transported from the RFQ to the end of MEBT, using calculated quadrupole settings and with the buncher and steering off. Beam current will be maximized on the Faraday cup using quadrupoles and correctors.

The LEBT to RFQ matching can then be adjusted by looking for the maximum output current while varying LEBT settings: energy, lens settings, and beam position. Finally the dependence of output current on input RFQ power will be measured and compared with the reference curve. If no considerable discrepancy is observed we can assume that the output beam has the same parameters as were measured during commissioning on the EBIS test stand.

The MEBT buncher will next be set, using the fast Faraday cup (FFC) temporarily installed on the end of the MEBT line. Buncher amplitude will be calibrated via measurement of the phase shift of the beam on the FFC vs. buncher phase, for different amplitude settings. Buncher phase is then set, again looking at the FFC. The performance is compared with calculations.

3.3 Validation of Linac beam specification

First, beam will be transported to the first diagnostic box in the HEBT using calculated RF power, phase, and quadrupole triplet settings. The beam current will then be maximized on the CT using the MEBT and linac correctors and quadrupoles. A fast Faraday cup (GHz) and an emittance measuring device installed in this diagnostic box will allow characterization of the linac and buncher by comparing output beam parameters with calculated values. This will be done using He^{1+} and He^{2+} beams, to avoid the confusion arising from the acceleration of multiple charge states with heavier beams.

3.4 Validation of the HEBT beam specifications

An ion beam with RFQ output energy (300 keV/amu) will first be transported to the diagnostic box between the HEBT dipoles with calculated quadrupole settings, and with buncher and linac RF power off. The beam centroid will be set close to zero by using correctors and beam profiles monitors in the HEBT. The RFQ amplitude will be set by maximizing the beam current of the desired ion species and charge state.

The ion beam will then be transported to the Faraday cup between the HEBT dipoles with the linac power on and calculated quadrupole setting for 2 MeV/amu. The beam centroid will be set close to zero by using correctors and beam profiles monitors in the HEBT. The linac amplitude and phase will then be set by maximizing the ion beam current of the desired ion species between the HEBT dipoles.

Finally, MEBT and HEBT bunchers will be powered, and the energy spread of the desired ion species minimized by looking at the beam size at the multiwire between the dipoles, where resolution is maximum.

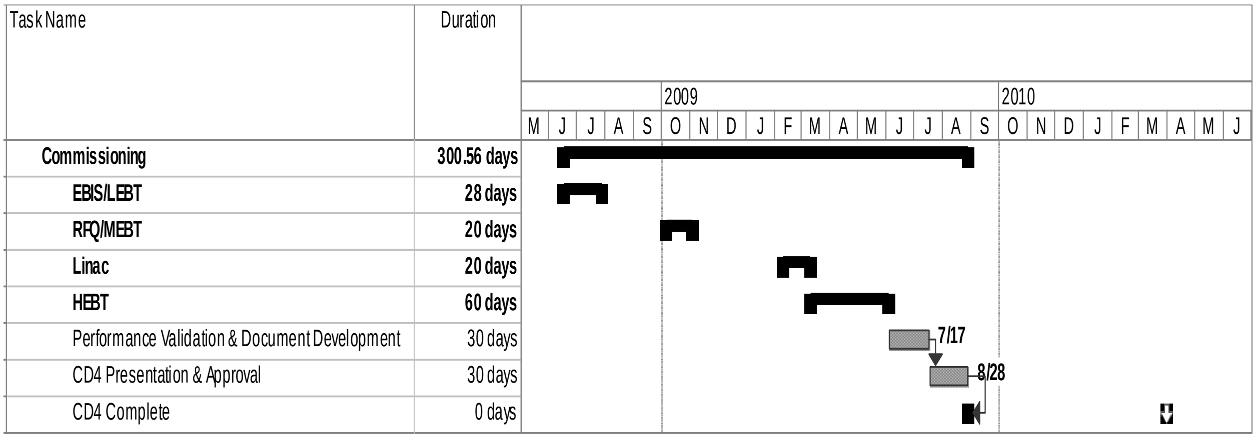
Appendix A

Start-Up Plan Summary Form

The following is the listing of start-up plan experiments:

TASK		Contact	Duration
1	**EBIS and LEBT commissioning**		
1.1	External Beam into EBIS	Beebe	3 days
1.2	Steering correction for external ion beam	Beebe	
1.3	Ion extraction into LEBT and transport to LEBT_CT2	Beebe	5 days
1.4	Steering corrections for extracted ion beam	Beebe	
1.5	Tuning of electrostatic lens and LEBT solenoid	Beebe	
1.6	Emittance measurement	Beebe	4 weeks (50%)
1.7	Matching into RFQ	Beebe	
2.0	**RFQ and MEBT Commissioning**		
2.1	Beam transport to end of MEBT	Raparia	4 weeks
2.2	LEBT steering	Raparia	
2.3	MEBT steering	Raparia	
2.4	Input match into RFQ	Raparia	
2.5	RFQ transmission vs. EBIS extraction voltage	Raparia	
2.6	RFQ transmission vs RFQ power	Raparia	
2.7	MEBT buncher setup	Raparia	
3.0	**Linac Commissioning**		
3.1	Beam transport to HEBT_CT1	Raparia	4 weeks
3.2	Tuning of quadrupole triplets in Linac	Raparia	
3.3	MEBT steering corrections	Raparia	
3.4	Bunch shape measurements on fast FC using He^{1+} and He^{2+}	Raparia	
4.0	**HEBT Commissioning**		
4.1	RFQ beam (300 keV/amu) transported to HEBT_FC2	Raparia	3 months (50%)
4.2	Steering corrections	Raparia	
4.3	RFQ amplitude setting	Raparia	
4.4	Linac beam (2MeV/amu) transport to HEBT_FC2	Raparia	
4.5	Steering corrections	Raparia	
4.6	Perform beam-related radiation safety fault studies	Raparia	
4.7	Linac amplitude and phase setting	Raparia	
4.8	Minimize the energy spread by varying MEBT and HEBT bunchers and looking at MW2	Raparia	
4.9	Maximize intensity at HEBT_FC2 for desired species	Raparia	

Appendix B
Present Commissioning Schedule



Following EBIS/LEBT commissioning, the RFQ is installed. A temporary diagnostic box is placed at the end of MEBT.

Following RFQ/MEBT commissioning, the Linac is installed (HEBT already in place).

A ramp up to “optimum performance” would be expected to occur within 6 months after the completion of CD4.

Appendix C

Start-up Plan
TASK 2.6
RFQ Transmission vs RFQ Power

The purpose of this task is to establish one of the basic operating parameters of the RFQ and compare with theoretical calculations.

Initially, beam is transported to the end of MEBT, orbit corrections in LEBT and MEBT are completed, and maximum beam current at MEBT-CT1 is obtained. RFQ power will then be varied from 5% to 110% for the desired ion species, and current will be monitored and recorded at MEBT-CT1.

Compare this current vs RF power curve with theoretical calculations.

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TASK 4.8
Energy Spread Minimization at HEBT-MW2

The purpose of this task is to determine the minimum achievable energy spread at the HEBT-MW2 for the desired ion species.

Before measuring the energy spread at the HEBT-MW2 the following steps must be completed:

(1) Linac beam transported to HEBT-FC2
(2) Orbit corrected in the HEBT
(3) Linac phase and amplitude is set
(4) Neighboring charge states are separated
(5) Desired charge state is tuned to the HEBT-MW2

The Dispersion function at the HEBT-MW2 is 1.2 meters, and the horizontal beta function is 0.079 meters. This gives a resolution of 650 for an unnormalized emittance of 11 π mm mrad. A grid search will be performed for the amplitude of MEBT and HEBT bunchers, namely MEBT-B1, HEBT-B1 and HEBT-B2. Once the minimum horizontal beam size on the HEBT-MW2 is obtained, the energy spread can be calculated.